CHAPTER 4

EPA/NSF ETV
EQUIPMENT VERIFICATION TESTING PLAN FOR ULTRAVIOLET RADIATION TECHNOLOGIES FOR INACTIVATION OF MICROBIOLOGICAL CONTAMINANTS

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1.0 APPLICATION OF THIS VERIFICATION TESTING PLAN

This document is the NSF Equipment Verification Testing Plan for evaluation of water treatment equipment utilizing ultraviolet (UV) light for inactivation of microorganisms. This Testing Plan is to be used as a guide in the development of the Field Operations Document (FOD) for testing UV equipment, within the structure provided by the NSF Protocol entitled "Protocol For Equipment Verification Testing for Inactivation of Microbiological Contaminants". This Environmental Technology Verification (ETV) Testing Plan is applicable only to treatment systems that rely on UV light to effectively inactivate microorganisms. Systems may incorporate unique strategies for enhancing the effect of UV light on target organisms, such as by applying innovative lamp technologies. All UV technologies including their UV lamps. Reactors and Irradiance sensors may be tested under this plan.

In order to participate in the equipment verification process for inactivation by UV, the equipment Manufacturer shall employ the procedures and methods described in this test plan and in the referenced NSF Protocol as guidelines for the development of the Manufacturer's Field Operations Document. Interim, non-standard methods for assessing the viability of cyst and oocyst after UV treatment may be used for verification. However, any interim method (see Appendix A) is subject to change and must have been reviewed by experts of cyst and oocyst viability.

Various types of water treatment equipment employ UV light for several water purification objectives, including removal of trace organic contaminants through advanced oxidation processes and microbiological disinfection (inactivation). This Test Plan is applicable to the testing of water treatment equipment utilizing UV light for inactivation of microorganisms in drinking water. Because particles and other dissolved UV light absorbing contaminants can interfere with UV light and reduce its disinfecting efficiency, this plan is applicable to the use of UV technology for treating high quality water (<10 Nephlometric Turbidity Units (NTU) turbidity and >70% transmittance at 1 cm are the minimum qualities recommended) sources, including

- treated surface water supplies of consistent high quality;
- groundwater supplies that are high in percent transmittance of filtered and unfiltered water or have been pre-treated to produce water of consistent high quality.

2.0 INTRODUCTION

UV light currently is being used in place of chlorine for secondary wastewater disinfection in the eastern United States, and is gaining increased attention as a disinfectant for water reuse projects in California. UV technology also is used for drinking water applications in Europe for several reasons:

- It is a physical process that does not involve the addition of chemicals.
- It has been demonstrated to be a highly effective germicide.
- It employs very short contact time (seconds) in pressurized reactors making capital costs low and maintaining existing hydraulic gradients without the need for re-pumping.
- In numerous studies to date it has been shown to produce no disinfection by-products.

The typical sources of UV light are low pressure, mercury vapor arc lamps. These lamps produce approximately 90 percent of their total energy output at the germicidal wave length of 253.7 nanometers (nm). Low pressure UV technology has been employed in wastewater treatment and some drinking water treatment applications for inactivation of certain bacteria and viruses. Conventional low pressure UV systems have not been found to be effective at killing cysts and oocysts of protozoa such as *Giardia* and *Cryptosporidium* at cost effective dosages. Other UV technologies (including medium pressure, high intensity, advanced, and pulsed) are being developed for the inactivation of more resistant microorganisms, such as protozoan cysts and oocysts. Little is known about which wavelength(s) result in the inactivation of the protozoan cysts and oocysts by high pressure, advanced and pulsed UV technologies. Nonetheless, this NSF Equipment Verification Testing Plan is applicable to any UV technology.

3.0 GENERAL APPROACH

Testing of equipment covered by this Test Plan will be conducted by an NSF-qualified Field Testing Organization that is selected by the equipment Manufacturer. Water quality and microbiological analytical work to be carried out as a part of this Test Plan will be contracted with a laboratory certified by a state or accredited by a third party organization (i.e., NSF) or the U.S. Environmental Protection Agency (U.S. EPA) for the appropriate water quality parameters.

4.0 OVERVIEW OF TASKS

The following section provides a brief overview of the recommended tasks that may be included in Initial Operations and of the required and optional tasks to be included in any UV inactivation Test Plan.

4.1 Initial Operations: Overview

The purpose of these tasks is to provide preliminary information which will facilitate final test design and data interpretation.

4.1.1 Task A: Characterization Of Feed Water

The objective of this recommended Initial Operations task is to obtain a chemical, biological and physical characterization of the feed water. A brief description of the watershed or aquifer and any pretreatment modules that provide the feed water shall be prepared, to aid in interpretation of feed water characterization.

4.1.2 Task B: Initial Tests Runs

During Initial Operations, the equipment Manufacturer may want to evaluate equipment operation and determine flow rates, hydraulic retention time, contact times (via tracer tests when technically feasible as many advanced UV systems have theoretically short retention times of 2 to 20 seconds), number of UV lamps, the spectral distribution of wavelength from the UV lamp or other factors which provide effective treatment of high

quality water. This is a recommended Initial Operations task. The equipment Manufacturer may also want to work with the Testing Organization and analytical laboratory to perform blank or preliminary challenges and sampling routines to verify that sampling equipment can perform its required functions including laboratory studies of UV irradiance and microorganism viability. This is also a recommended Initial Operations Task.

4.2 Verification Operations: Overview

The objective of this task is to operate the treatment equipment provided by the equipment Manufacturer and to assess its ability to meet stated water quality goals and any other performance characteristics specified by the Manufacturer. A minimum of one verification testing period shall be performed. Additional verification testing periods may be necessary to verify the manufacturer's claims, such as in the treatment of surface water where additional testing during each season may assist in verifying a claim. The time period selected for testing should represent the worst-case for concentrations of contaminants e.g., dissolved solids which interfere with UV, or potentially can foul a UV lamp or sensor e.g., iron, nitrates.

4.2.1 Task 1: Verification Testing Runs and Routine Equipment Operation

To characterize the technology in terms of efficiency and reliability, package plant water treatment equipment that includes UV lamp, reactor and sensor for measuring UV Irradiance shall be operated for Verification Testing purposes with the operational parameters based on the results of the Initial Operations testing.

4.2.2 Task 2: Feed Water and Finished Water Quality

During each day of Verification Testing, feed water and treated water samples shall be collected, and analyzed for parameters relevant to microbial enumeration or those affecting equipment performance, as outlined in Section 10.0, Table 1.

4.2.3 Task 3: Documentation of Operating Conditions and Treatment Equipment Performance

During each day of Verification Testing, operating conditions and performance of the water treatment equipment shall be documented. This includes UV Irradiance, lamp and sensor fouling and cleaning applied and frequency, water flow (rate [g.p.m.] and total flow), power usage, stability of power supply (surges, brown-outs, etc.).

4.2.4 Task 4: Microbial Inactivation

The objective of this task is to measure the performance of the UV drinking water treatment equipment that includes the UV lamp and reactor, in inactivating microbiological contaminants during Verification Testing.

4.2.5 Task 5: Data Management

The objective of this task is to establish an effective field protocol for data management at the field operations site and for data transmission between the Field Testing Organization (FTO) and the NSF for data obtained during the Verification Testing. Prior to the beginning of field testing, the database design must be developed by the Field Testing Organization and reviewed and approved by NSF. This will insure that the required data will be collected during the testing, and that it can be effectively transmitted to NSF for review.

4.2.6 Task 6: Quality Assurance/Quality Control (QA/QC)

An important aspect of Verification Testing is the protocol developed for quality assurance and quality control. The objective of this task is to assure accurate measurement of operational and water quality parameters during UV radiation equipment Verification Testing. Prior to the beginning of field testing, a QA/QC plan must be developed which addresses all aspects of the testing process. Each water quality parameter and operational parameter must have appropriate QA and QC measures in place and documented. For example, the protocol for pH measurement should describe how the pH meter is calibrated (frequency, pH values), what adjustments are made, and provide a permanent record of all calibrations and maintenance for that instrument.

5.0 TESTING PERIODS

The required tasks in the Verification Testing Plan (Tasks 1 through 6 except Task 4 when package water treatment equipment is being used to deliver potable water at the test site; see section 9 Routine Equipment Operation) are designed to be carried out for a minimum of one verification testing period. Additional verification testing periods may be necessary to verify the manufacturer's claims, such as in the treatment of surface water where additional testing during each season may assist in verifying a claim. For systems treating solely groundwater or surface waters of consistent quality due to pre-treatment (<10 NTU turbidity and >70% transmittance), one verification testing period may be sufficient. If one verification testing period is selected, the feed water should represent the worst-case concentrations of contaminants which can verify the manufacturer's claims. For example dissolved solids which interfere with UV, or potentially can foul a UV lamp or sensor (e.g., iron, nitrates). Although one testing period satisfies the minimum requirement of the ETV program, manufacturers are encouraged to use additional testing periods to cover a wider range of water quality conditions.

Verification testing periods consist of continued evaluation of the treatment system using the pertinent treatment parameters defined in Initial Operations. Performance and reliability of the equipment shall be tested during Verification Testing periods of a minimum of 320 hours (13 full days plus one 8-hour shift). Only Task 3 shall be conducted during a 27-day period. The purpose of the 27 day test period is to assess operation and maintenance items associated with the equipment, such as the build up of potential scale or other contaminants on the surface of UV lamps and UV irradiance sensors.

6.0 DEFINITION OF OPERATIONAL PARAMETERS

Definitions that apply to UV processes are given below:

6.1 UV Output

The amount of power (in the wavelength range of 200-300 nm) delivered from the lamp to the water and described in terms of watts (W) per lamp. The absolute free-standing UV power of the lamp is decreased by end losses and by transmission losses through the quartz sleeve. The UV output can be reduced because of lamp aging, water temperature, and lamp fouling (as defined in Section 6.7).

6.2 UV Irradiance

The rate at which UV energy is incident on a unit area (e.g., 1 cm^2) in the water and described in terms of UV power per unit area, e.g., microwatts per square centimeter ($\mu W/cm^2$) or milliwatts per square centimeter (mW/cm^2).

6.3 UV Dose

The energy is quantified to a dose by multiplying the UV Irradiance by the actual exposure time:

Dose (μW sec/cm^2) = UV Irradiance ($\mu W/cm^2$) x Time (seconds)

6.4 UV Transmittance

The ability of the water to transmit UV light. Transmittance of a water sample is generally measured as the percentage (%T) of transmitted light (I) to incident light (I_0) through an operationally defined pathlength (L). Many commercially available spectrophotometers actually report the Absorbance (A) for a fixed pathlength (L) of the sample. Percent Transmittance and Absorbance can be related as: $\%T = 100 \times 10^{-(A/L)}$. Many naturally occurring organic and inorganic constituents (e.g., natural organic matter, iron, nitrate) will absorb energy in the UV wavelengths, thus reducing the transmittance of the water. This reduced transmittance often interferes with the disinfection efficiency of a UV disinfection system.

6.5 Low Pressure Lamps

Low pressure lamps operate at a temperature between 38 and 49°C (100 and 120°F) to produce a near monochromatic radiation at 253.7 nm. These lamps typically have a linear power density of about 0.3 W/cm.

6.6 Medium Pressure Lamps

Medium pressure lamps produce a high intensity broad spectrum of UV light (extending over the 200-300 nm range of microbiological sensitivity with a maximum output at about 255 nm) with a higher Irradiance and operating at a much higher operating temperature (surface temperatures >500°C) than do low pressure Hg lamps. The linear power density is also much higher (typically 100-300 W/cm).

6.7 Lamp Fouling

If the lamps are submerged in the feedwater, lamp fouling may occur. Lamp fouling is the reduction in UV Irradiance caused by the presence of certain organic and inorganic ions in the water that can result in the accumulation of mineral deposits or biofilm on the quartz sleeves covering the lamps. Chemical or mechanical cleaning is needed to restore the UV Irradiance to design conditions.

7.0 TASK A: CHARACTERIZATION OF FEED WATER

7.1 Introduction

This Initial Operations task is needed to determine if the chemical, biological and physical characteristics of the feed water are appropriate for the water treatment equipment to be tested.

7.2 Objectives

The objective of this task is to obtain a complete chemical, biological and physical characterization of the source water or the feed water as pre-treated that will be entering the treatment system being tested.

7.3 Work Plan

The specific parameters needed to characterize the water will depend on the equipment being tested and the source water feeding the UV drinking water treatment equipment During this Initial Operations task, the feed water to the UV drinking water treatment systems, the following characteristics should be measured and recorded:

- Water Temperature, Turbidity, UV_{254} absorbance and filtered and unfiltered transmittance (and/or absorbance measurements at other wavelengths that are appropriate to the UV disinfection system being tested), Free and Total Chlorine, Total Organic Carbon, and Color.
- Total Coliform, aerobic spores, and Algae.
- Total Alkalinity, pH, Calcium, Hardness, Nitrate, aluminum and Iron.

Section 9 of this document provides a list characteristics that shall be measured and recorded depending on the source of feed water to the UV equipment and should be used as a guideline for Initial Operations.

Sufficient information shall be obtained to illustrate the variations expected to occur in these parameters that will be measured during the Verification Testing for a typical annual cycle for the water source. This information will be compiled and shared with NSF so NSF and the Testing Organization can determine the adequacy of the data for use as the basis to make decisions on the testing schedule. Failure to adequately characterize the feed water (source water) could result in testing at a site later deemed inappropriate, so the initial characterization will be important to the success of the testing program.

A brief description of the watershed or aquifer source shall be provided, to aid in interpretation of feed water characterization. The watershed description should include a statement of the approximate size of the watershed, a description of the topography (i.e. flat, gently rolling, hilly, mountainous) and a description of the kinds of human activity that take place (i.e. mining, manufacturing, cities or towns, farming) with special attention to potential sources of pollution that might influence feed water quality. The nature of the water source, such as stream, river, lake or man-made reservoir, should be described as well. Aquifer description should include the above characterization relative to the recharge zone, a description of the hydro geology of the water bearing stratum(a), well-boring data, and any Microscopic Particulate Analysis data indicating whether the groundwater is under the influence of surface waters.

Any pretreatment modules impacting the source water shall be characterized. Any coagulant or other chemical additions shall be identified. Predicted effects on turbidity and particle load by pre-filtration shall be discussed.

7.4 Evaluation Criteria

Feed water quality will be evaluated in the context of the Manufacturer's statement of the equipment performance capabilities but should not be beyond the range of water quality suitable for treatment for the equipment in question. If the device is to be used for treating high quality ground waters or those surface water sources which have already received full or partial treatment, it should be tested on waters of that quality.

8.0 TASK B: INITIAL OPERATIONS

8.1 Introduction

During Initial Operations, a Manufacturer may want to evaluate equipment operations and determine the flow rates, hydraulic residence time, pulse rates, exposure times, number and/or Irradiance of UV lamps, the spectral distribution of wavelength from the UV lamp, degree of power supply/line conditioning required, or other factors applicable to the technology which provide effective treatment of the feed water. The Manufacturer may also want to work with the Testing Organization and the analytical laboratory to perform blank or preliminary challenges and sampling routines to verify that sampling equipment can perform their required functions under normal operating conditions. This information may also indicate operating conditions under which the Manufacturer's stated performance capabilities are not met, or whether any threshold UV dose level can be determined. This is a recommended Initial Operations task. An NSF field inspection of equipment operations and sampling and field analysis procedures may be carried out during the initial test runs.

The "Protocol for Equipment Verification Testing of Microbiological Contaminant Inactivation by Packaged and/or Modular Drinking Water Treatment Systems For Small Public or Private Water Supplies" (Chapter 1) under which this test plan is formulated requires hydraulic testing to demonstrate flow conditions and residence duration (exposure time). The equipment Manufacturer may want to conduct such tests during these initial runs. Additional tracer tests are required if a pilot system is hydraulically dissimilar to that tested for the Protocol is utilized, or if

testing is to proceed at flow rates and conditions other than those demonstrated previously. Procedures for developing a tracer test methodology are described in the Protocol.

8.2 Objectives

The objective of these test runs is to bracket the proper operating parameters for treatment of the feed water during Verification Testing. UV performance may be different for feed waters from different test sites or for the feed water from the same site during different seasons. Therefore, conducting initial test runs is strongly recommended.

8.3 Work Plan

Conducting UV exposure tests on small batches (cuvettes) of feed water containing test organism can be a rapid method of roughly evaluating equipment performance and of bracketing effective UV dosages. Where batch testing cannot be applied to a particular system, scaled back or full-scale initial tests may be designed. Follow-up confirmation of initial batch testing by preliminary scaled back continuous flow tests is recommended. Continuous flow testing is required during verification testing unless the manufacturer's performance claim also specifies use during intermittent flow or use as typical for very small community systems (<500 persons). The work plan should then include a shut down period of 12 hours each day where the UV equipment is turned off.

8.4 Analytical Schedule

Because these runs are being conducted to define operating conditions for Verification Testing, a strictly defined schedule for sampling and analysis does not need to be followed. Adhering to the schedule for sampling and analysis to be followed during Verification Testing would be wise, however, so the operator can gain familiarity with the time requirements that will be applicable later on in the test program. Also, during the Initial Operations phase, the verification organization may conduct an initial on-site inspection of field operations, sampling activities and on-site analysis. The sampling and analysis schedule for Verification Testing shall be followed during the on-site inspection.

8.5 Evaluation Criteria

The Manufacturer should evaluate the data produced during the Initial Operations to determine if the water treatment equipment performed so as to meet or exceed expectations based on the statement of performance capabilities. If the performance was not as good as the statement of performance capabilities, the Manufacturer may wish to conduct more Initial Operations or to cancel the testing program.

9.0 TASK 1: VERIFICATION TESTING RUNS AND ROUTINE EQUIPMENT OPERATION

9.1 Introduction

Package plant water treatment equipment that includes UV lamp, reactor and sensor for measuring the UV light Irradiance shall be operated for Verification Testing purposes with the operational parameters based on the manufacturer's statement of performance capabilities.

9.2 Experimental Objectives

The objective of this task is to characterize the technology in terms of efficiency and reliability while operating under the conditions established during the Initial Operations testing. These conditions must represent the operating conditions for which the unit was designed. For example, if the unit is designed to operate at several hundred g.p.m., the testing must be done using flow rates which approximate these conditions. However, if the unit has a family of similar units that differ only in size and the Manufacturer demonstrates with tracer data, calculations, computation, fluid dynamic models, etc., that a smaller unit has the same hydraulic behavior and irradiance distribution as the larger unit, then testing may proceed with the smallest size unit. The experimental protocol must be designed so as to assess the unit adequately when operating under its design conditions.

9.3 Work Plan

9.3.1 Verification Testing Runs

The Verification Testing Runs in this task consist of continued evaluation of the treatment system, using the most successful treatment parameters defined in Initial Operations. Performance and reliability of the equipment shall be tested during Verification Testing periods of a minimum of 320 hours (13 full days plus one 8-hour shift). Only Task 3 shall be conducted during a 27 day period. The purpose of the 27 day test period is to assess the build up of potential scale or other contaminants on the surface of UV lamps and UV Irradiance sensors. During each testing run, Tasks 1 through 5 shall be conducted simultaneously.

Seasonal testing may be required for equipment treating surface waters because of the differences in water quality that occur on a seasonal basis, although pre-treatment modules, when present, may damp these variations. For UV treatment equipment, factors that can influence treatment performance include:

- High turbidity, often occurring in spring, encountered in rivers carrying a high sediment load or in surface waters during periods of high runoff resulting from heavy rains or snow melt. Particulate load may absorb or interfere with UV radiation.
- Algae, which may exhibit bloom on a seasonal basis. Algae absorb and interfere with UV radiation.
- Natural organic matter, which may be higher in some waters in the fall. Organic matter may absorb UV radiation, and may contribute to fouling of the lamp surfaces.

- Iron, nitrate, pH, alkalinity and hardness, which may vary seasonally for some waters. These parameters may cause or contribute to fouling of the lamp surfaces or may absorb UV radiation.
- Aluminum from alum coagulation treatment of surface water, hardness from lime softening, may contribute to fouling of the lamp surfaces.

It is unlikely that all of the above problems would occur in surface water during a single season, and this may result in testing during each season of the year and possibly at different test sites. The testing should be designed to test the UV unit when the water quality to that unit changes, either because the unit is operated without pre-treatment or because the pre-treatment produces a different quality water which is presented to the UV unit.

9.3.2 Routine Equipment Operation

If the package water treatment equipment is being used for production of potable water, in the time intervals between verification runs, routine operation for water production is anticipated. In this situation, the operating and water quality data collected and furnished to the Safe Drinking Water Act (SDWA) primacy agency shall be supplied to the NSF-qualified testing organization.

9.4 Schedule

During Verification Testing, water treatment equipment shall be operated continuously for a minimum of 320 hours (13 full days plus one 8-hour work shift) with interruptions in operation as needed for system maintenance.

9.5 Evaluation Criteria

The goal of this task is to operate the equipment for the 320 hour period, including time for lamp changing and other necessary operating activities, during Verification Testing. Data shall be provided to substantiate the operation for 320 hours or more.

10.0 TASK 2: TEST RUNS FOR FEED WATER AND FINISHED WATER QUALITY

10.1 Introduction

Water quality data shall be collected for the feed water and treated water as shown in Table 1 depending upon the source of feed water (see 10.1.1- 10.1.3), during each day of Verification Testing. The Field Test Organization on behalf of the equipment Manufacturer shall assure the sampling or measuring of the water quality parameters in Table 1 depending upon the source of feed water (see 10.1.1- 10.1.3). A Field Testing Organization may use local personnel to assist in collection of samples or measurement of test parameters, but is responsible for their training to assure proper technique. Water quality goals and target inactivation goals for the water treatment equipment shall be recorded in the Field Operations Document in the statement of capabilities.

10.1.1 Untreated Surface Water as Feed Water:

For UV drinking water treatment systems that treat raw or filtered only surface water, the parameters in Table 1 shall be measured and recorded, except free and total chlorine and aluminum as these parameters will not likely occur in raw water (they will likely occur or be added during chemical treatment).

10.1.2 Treated Surface Water as Feed Water:

For UV drinking water treatment systems that treat feed water from consistently and previously treated (lime softening, chemical coagulation etc. but not solely filtration) surface water, the parameters in Table 1 shall be measured and recorded, except algae and endospores as previous treatment will likely have removed these contaminants.

10.1.3 Ground Water as Feed Water

For UV drinking water treatment systems that treat ground water, the parameters in Table 1 shall be measured and recorded, except color, algae and endospores as they will not likely occur in ground water, and free and total chlorine and aluminum which are not typically added during chemical treatment of ground water.

Table 1. Water Quality Sampling and Measurement Schedule

Parameter:	**Frequency:**
Temperature	Daily
pH	Daily
Total Alkalinity	Semi-weekly
Hardness	Semi-weekly
Total Organic Carbon	Semi-weekly
UV Absorbance (254 and/or other nm)	Semi-weekly
Turbidity	Daily at bench to check continuous Turbidimeters
Algae, number and species	Semi-weekly if no algae bloom. Daily if algae bloom occurs.
True Color	Semi-weekly
Nitrate	Semi-weekly
Iron, Manganese and Aluminum	Semi-weekly
Bacteria and viruses	Daily specified in capabilities statement and Total Coliform, or *Bacillus* spores
Free and Total Chlorine	Daily

10.2 Experimental Objectives

For verification testing of inactivation of naturally existing microorganisms this task will allow determination of mean concentrations of organisms and their variability in the feed water. A list of a minimum number of additional water quality parameters to be monitored during equipment verification testing is provided in the Analytical Schedule section below and in Table 1. The actual water quality parameters selected for testing shall be stipulated by the Manufacturer in the Field Operations Document and shall include all those necessary to permit verification of the statement of performance capabilities.

10.3 Work Plan

The manufacturer will be responsible for establishing the plant testing operating parameters, on the basis of the Initial Operations testing. Many of the water quality parameters described in this task will be measured on-site by the NSF-qualified Field Testing Organization or by local community personnel properly trained by the Field Testing Organization (refer to Table 2). Analysis of the remaining water quality parameters will be performed by a laboratory that is certified, accredited or approved by a State, a third-party organization (i.e., NSF), or the U.S. EPA. The methods to be used for measurement of water quality parameters in the field are listed in the Analytical Methods section below in Table 2. The analytical methods utilized in this study for on-site monitoring of feed water and filtered water qualities are described in Task 6, Quality Assurance/Quality Control (QA/QC). Where appropriate, the *Standard Methods* reference numbers for water quality parameters are provided for both the field and laboratory analytical procedures.

10.4 Water Quality Sample Collection

Water quality data shall be collected at regular intervals during each period of testing, as noted in this section. Additional sampling and data collection may be performed at the discretion of the Manufacturer. Sample collection frequency and protocol shall be defined by the Field Testing Organization in the Field Operations Document.

In the case of water quality samples that will be shipped to the off-site laboratory for analysis, the samples shall be collected in appropriate containers (containing preservatives as applicable) prepared by the off-site laboratory. These samples shall be preserved, stored, shipped and analyzed in accordance with appropriate procedures and holding times, as specified by the analytical laboratory. Original field sheets and chain-of-custody forms shall accompany all samples shipped to the analytical laboratory. Copies of field sheets and chain-of-custody forms for all samples shall be provided to NSF.

10.5 Analytical Schedule

During Verification Testing of UV treatment equipment, the feed water and treated water quality shall be characterized by measurement of the water quality parameters listed above in the Table with the exceptions allowed under sections 10.1.1 - 10.1.3. For assessing cyst and oocyst viability, the interim methods described in Appendix A may be used when verifying inactivation of protozoa contaminants. These parameters are listed to provide State drinking water regulatory agencies with background data on the quality of the feed water being treated and the quality of

the treated water. These data are to be collected to enhance the acceptability to the Verification Testing data to a wide range of drinking water regulatory agencies.

Table 2: Analytical Methods

Parameter	**Facility**	***Standard Methods* and Other Method References**	**EPA Methods**
Temperature	On-site	2550 B	
pH	On-site	4500 H+ B	150.1/150.2
Total Alkalinity	Lab	2320 B	
Total Hardness	Lab	2340 C	
Total Organic Carbon	Lab	5310 C	
UV Absorbance (254 and/or other nm)	Lab	5910 B	
Turbidity	On-site	2130 B	180.1
Algae, number species	Lab	10200 and 10900	
True Color	Lab or On-site	2120 B (Hach Co. modification of *SM* 2120 measured at 455 nm)	
Total Coliform	Lab	9221/ 9222/9223	
E. coli	Lab	9225 or Colilert	
Micrococcus luteus	Lab	AWWARF Surrogate Report by CSU	
Bacillus spores	Lab	Rice et al. 1996	
MS2 Virus	Lab	EPA ICR Method for Coliphage Assay, 1996	
Algae	Lab	AWWARF Surrogate Report by CSU	
Giardia and *Cryptosporidium*	Lab	EPA Draft 1622, (enumeration only)	
Iron	Lab	3120 B, 3111 B, 3113 B	200.7, 200.9
Nitrate	Lab	4110 B, 4500-No_3-F, 4500-No_3-D, 4500-No_3-E	300.0, 353.2
Free and Total Chlorine	On-site	Hach modification of *SM* 4500 CL:G	

10.6 Evaluation Criteria

Evaluation of water quality in this task is related to meeting the requirements of the SDWA, including future regulations (e.g., Ground Water Disinfection Rule) and existing regulations,

(e.g., Surface Water Treatment Rule) for plants that employ UV radiation, plus any general water quality capabilities indicated by the Manufacturer.

11.0 TASK 3: DOCUMENTATION OF OPERATING CONDITIONS AND TREATMENT EQUIPMENT PERFORMANCE

11.1 Introduction

Task 3 shall be conducted over a minimum 27 day period. During each day of the testing period operating conditions shall be documented. This shall include descriptions of pretreatment chemistry and filtration for the package plant processes used, if any, and their operating conditions. The performance of the UV disinfection equipment shall be documented, including total water throughput and total power usage, UV Irradiance as measured by the manufacturer's UV irradiance sensor, hours of lamp operation, lamp sensor output and its decrease in output over time, frequency of pulsing or length of cycles, if applicable, lamp fouling rates, frequency and type of mechanical cleaning and performance of automatic mechanical wipers or ultrasonic cleaners, if present. In addition, the power supply shall be tracked and spikes and brownout events shall be noted.

The measurement of true UV dose will not be measured as part of the equipment operating performance. The hydraulics and UV irradiance distribution vary greatly and would confound the UV dose calculation. UV irradiance measurements shall be measured for low pressure UV lamp equipment. For equipment using other UV technology, the operating conditions and equipment performance shall be monitored using the sensor provided with the UV package plant (lamp, sensor and reactor). Any change in reactor design, source of lamp or UV irradiance sensor constitutes a change in the UV package plant and repeat testing shall be required.

11.2 Objectives

The objective of this task is to accurately and fully document the operating conditions that applied during treatment, and the performance of the equipment. This task is intended to result in data that describe the operation of the equipment and data that can be used to develop cost estimates for operation of the equipment.

11.3 Work Plan

During each day of Verification Testing, treatment equipment operating parameters for both pretreatment and UV radiation will be monitored and recorded on a routine basis. This shall include a complete description of pretreatment chemistry; rate of flow and total flow; and UV irradiance as measured by the manufacturer's UV irradiance sensor. Calibration of lamp irradiance sensors shall be demonstrated and recorded. Electrical energy consumed by the UV treatment equipment shall be measured and recorded. In addition, the aggregate horsepower of all motors and mechanical efficiencies of all motor/devices supplied with the equipment shall be determined and used to develop an estimate of the maximum power requirements and routine power consumption during operation. A complete description of each process shall be given, with data on volume and detention time of each process stream at rated flow.

An automatic device for monitoring UV irradiance is strongly suggested with any UV system. The testing plan should include a determination of the minimum irradiance below which equipment shutoff should occur to assure adequate disinfection at all times. When the irradiance drops below this value, flow can be shut off or a signal given to the operator indicating the need for cleaning or lamp replacement.

11.4 Schedule

Table 3 presents the schedule for observing and recording UV package plant operating and performance data.

Table 3 Package Treatment Plant Operating Data

OPERATIONS PARAMETER	ACTION
Flow Rate	Check and record each 2 hours. Adjust when 10% above or below target. Record both before and after adjustment.
Exposure Time*	Record retention or cycle times when applicable. If variable, record degree of variation.
UV Irradiance	Check and record each 2 hours.
UV Sensor	Record out put from in-line monitor. Record changes in lamp irradiance following each cleaning
Lamp Fouling/Cleaning system	Record frequency of sleeve cleaning, if applicable
Lamp Hours	Record Daily
Electric Power	Record meter reading daily
Lamp Cycles	Record frequency of lamp on/off cycles
* Recording of exposure time is required for systems where exposure is independent of hydraulics or UV pulse rate. For others, exposure time will have been determined in preliminary tracer testing by other means for UV systems which have short hydraulic retention times and will not vary during operation.	

11.5 Evaluation Criteria

Where applicable, the data developed from this task will be compared to statements of performance capabilities. If no relevant statement of performance capability exists, results of operating and performance data will be tabulated for inclusion in the Verification Report.

12.0 TASK 4: DOCUMENTATION OF EQUIPMENT PERFORMANCE INACTIVATION OF MICROORGANISMS

12.1 Introduction

Inactivation of microorganisms is the primary purpose of UV drinking water treatment modules. Consequently, the effectiveness of the equipment at inactivating microorganisms introduced by seeding the feed water with bacteria, viruses or protozoa or with a combination of those or other approved types of microorganisms will be evaluated in this task. When the naturally occurring concentration of the microorganism in the feed water at a test site or where an UV package water treatment is delivering potable water, is sufficient to challenge the manufacturer's performance claim, no challenge test or seeding study is necessary. The measurement of inactivation is a comparison of the percent of viable organisms in the feed stream with the percent of viable organisms in the effluent.

12.2 Experimental Objectives

The objective of this task is to operate the treatment equipment provided by the Manufacturer and to characterize the technology in terms of efficacy at inactivation of microbial organisms. Challenge organisms to be tested will be selected by the equipment Manufacturer.

12.3 Work Plan

12.3.1 Microbial Challenge Tests

Microbial challenge experiments shall be conducted at full scale and not with pilot or prototype equipment. The Field Testing Organization shall conduct the challenge studies in the field, and the Field Testing Organization shall submit the resulting samples to a laboratory that is certified, accredited or approved by a State, a third-party organization (i.e., NSF), or the U.S. EPA.

For cysts and oocyst only, the microbial challenge test may be performed three times at the best operating conditions specified by the manufacturer and based on the results from the Initial Operations (section 5). Only one process control test (section 12.3.3.1) may be performed where the UV lamp is turned off. One microbial challenge test may also be performed at an operating condition less than the manufacturer recommends. This condition may be determined by increasing the flow through the reactor or decreasing the power to the UV lamp, i.e., reduce irradiance to less than optimum.

12.3.1.1 Organisms Employed for Challenge Experiments. Microorganisms which may be used for inactivation studies are listed below (see Appendix A for protozoan microorganisms). These species represent microorganisms of particular interest and concern to the drinking water industry, and represent a range of resistance to inactivation methods. The specific batch(es) used must be shown to be viable by the laboratory involved in the analytical aspects of the testing.

Bacteria	*Bacillus subtilis*	*Pseudomonas* spp.
	Clostridium perfringens	*E. coli*
Virus	MS2 bacteriophage (surrogate)	

12.3.1.2 Spiking Protocols. The total number of each type of test organism required for spiking will depend on the reactor volume, the water flow rate, and the desired steady-state concentration of microbiological contaminants in the reactor. For viruses, a steady-state final concentration adequate to show 4-log removal against the effluent analyses detection limit would be necessary to satisfy the Surface Water Treatment Rule (SWTR) requirement. The total number of organisms required to provide these steady-state microbiological populations will depend on the overall volume of the disinfection contractor, the detection limits of the sampling and analytical methods and the duration of experiments. For all organisms, the laboratory(ies) supplying the organisms and performing the viability studies shall be experienced in challenge testing and be able to predict initial dosages required to overcome any inherent experimental losses. Microbial challenges shall be conducted either by batch seeding or by feed stream injection. For evaluation of inactivation of *Giardia*, bacteria species, virus, or any other organisms negatively affected by chlorine, dechlorination will be required. Any system based on synergistic effects of chlorine and UV will not require dechlorination. Evaluation of *Cryptosporidium* inactivation will not require removal of chlorine when present in concentrations typical of drinking water (<5 mg/L) (see Appendix A).

12.3.1.3 Batch Seeding. A batch feed tank with sufficient volume to provide the proposed test volume shall be used. The discharge of the tank shall be situated so that 100% of the contents can be delivered to the system. The tank shall be filled with feed water which shall be dechlorinated, if necessary. Stirring of the feed water shall accompany dechlorination. Verification of dechlorination shall precede introduction of the seed organisms. Stirring of the feed tank shall precede seeding and continue throughout testing. Prior to microbial seeding of the tank, agitation procedures of the bulk seed container (as received from the supplier) such as vortexing and sonication shall be employed to assure organisms are not clumped together. A secondary source of feed water (dechlorinated, if necessary) sufficient to provide 3 retention time-equivalents (as determined by tracer tests or as defined by system functions) shall be available to add to the tank on its depletion. The purpose of this feed water will be to continue flushing seeded organisms through the system to the effluent sample ports.

12.3.1.4 In-line Injection. The feed to the test unit will be plumbed with a check-valve equipped injection port. If the feed stream is divided to parallel treatment units, mixing chamber shall be plumbed downstream of the injection port. A one Liter carboy equipped with a bottom dispensing port will feed this injection port by means of a

metering pump (diaphragm or peristaltic or equivalent) via siliconized or Teflon tubing. The pump shall be capable of fluid injection into the pressurized system feed line for the duration of the test, at a measurable and verifiable rate such that the one liter carboy is depleted coincident with the end of the test run. If dechlorination is necessary (see discussion, section 12.3.2.2), a chemical injection pump feeding a port and adequate contact mixing will be required upstream of the microorganism injection port. This pump will meter in a solution of sodium thiosulfate adequate to dechlorinate the feed water over the course of the test run.

The spike carboy will contain a magnetic stir bar and will be filled with one Liter of system water (dechlorinated if necessary) and placed on a stir plate. The prepared batch of spike organisms shall be agitated by methods such as vortexing and sonication and added to the stirring carboy. Once appropriate flow has been initiated through the test system, the test unit is operating properly, sample collection systems are readied, and complete dechlorination (<0.05 mg/L) has been verified at both the influent and effluent sample sites, the injection pump can be started. During the course of the test run, monitoring of the system flow rate and spike injection rate shall be performed and adjustments made to maintain test design.

12.3.2 Test Operation and Sample Collection

12.3.2.1 Test Stream Sampling. Sample ports shall be provided for the feed water stream (spiked with concentrations of microbiological contaminants) and the UV-treated water stream at the contactor effluent. The FTO shall specify the specific ways in which sample collection is performed according to the organisms that will be used for the proposed microbiological inactivation experiments. Examples of potential sample collection methods for bacterial, viral and protozoan organisms are provided below. The methods described, or any other peer-reviewed method may be used for verification testing. The FTO shall propose in the FOD the specific methods that are to be used for viability assessment of the selected microorganisms (See Section 12.4 below).

For bacterial and/or viral seeding experiments, methods for organism spiking and sample collection shall be consistent with a selected peer-reviewed method. The frequency and number of samples collected for each sampling point will be determined by the length of the test run and shall be specified by the FTO in the FOD. The volume of each ozone-treated water sample from the disinfection contactor effluent will depend on the concentrations of test organisms spiked, and the requirements of the analytical laboratory.

For protozoan spiking experiments, EPA Method 1622 or any other method that has been evaluated through the peer-reviewed process (e.g., Nieminski and Ongerth, 1995) may be followed for sample collection from the spiked water streams. The sample collection system shall be plumbed to allow installation of housings and filters for capture of sufficient flow for microbiological analysis. The FTO shall provide an indication of the recovery efficiency achievable under the sample collection method selected for use during protozoa seeding studies. The specific capture filter recovery system shall be fully described in the FOD by the FTO. In addition, the FOD shall include a plan of study for verification testing with a minimum of three standard recovery efficiency tests from the microbiological laboratory.

The sample tap(s) shall be sanitized with 95% ethanol one minute prior to initiating any bacteria or virus sample collection. Taps shall be flowing at the appropriate sample rate for at least one minute prior to sample collection.

12.3.2.2 Chlorine Residual Analysis. When dechlorinating, residual samples of the feed water shall be collected immediately after the grab samples or at regular intervals throughout the test run. These samples shall be analyzed for chlorine residual immediately. In *Giardia*, bacteria and virus inactivation tests where chlorine would affect test organisms and synergistic UV/chlorine effects are not being evaluated, any sample showing >0.05 mg/L residual will void the entire spike test.

12.3.2.3 Post-Test Sample Handling.. Filters shall then be handled and prepared for delivery to the analytical laboratory as directed by that laboratory. The Testing Organization shall then take steps to contain and/or sanitize any organisms remaining in the pilot system. Depending on the unit (design and materials), sanitization may be done using steam or hot water (80ºC for 10 min). The QA/QC plan should address how this sanitization procedure is to be done to insure inactivation of live organisms and subsequent removal of inactivated organisms from the unit, and biosafety concerns for both humans and the environment.

12.3.3 Experimental Quality Control

12.3.3.1 Process Control. A second round of testing shall be carried out identical to the above (12.3.1-12.3.2.3), with the UV lights turned off. The purpose of this testing is to evaluate any cumulative effects of the package plant stream, spiking and sampling processes, and sample handling on organism viability. This testing shall not occur until elimination of sanitizing agents and inactivated target organisms, whose presence could affect subsequent tests of the unit, has been demonstrated (12.3.2.4). The process control samples should show minimal inactivation of the target organism(s) relative to the trip control sample. Significant inactivation of the process control sample indicates that some aspect of the process other than UV contributes to inactivation of the test organism(s), and re-testing is required.

12.3.3.2 Trip Control. For tests utilizing spike challenges, a replicate or subsample of the spike dose shall accompany the actual spike dose from the analytical laboratory, including all preliminary processes of dose preparation pre-enumeration, shipping, and preparation for spiking, through return to the laboratory for enumeration and viability baseline assessment. The trip control samples should show minimal inactivation of the target organism(s). Significant inactivation of the trip control sample indicates that some aspect of the handling, from preparation to testing, contributed to inactivation of the test organism(s). Significant inactivation of trip control samples will require re-testing.

12.4 Microbiological Viability Analysis

Methods for assessing the viability of the selected bacteria and viruses (see Section 12.3.1.1) shall be specified by a laboratory that is certified, accredited or approved by the state, a third party organization (i.e., NSF) or the USEPA for the appropriate microbial analyses. Selected viability methods shall be specified by the FTO in the FOD.

Methods for assessing the viability of cysts and oocysts are non-standard but may be used in verifying claims that an UV system inactivates protozoan cysts and oocysts if the method has undergone peer review. A summary and comparison of viability methods is presented in research completed by the following researchers: Korich et al. (1993), Nieminski and Ongerth (1995), Slifko et al. (1997) and others (see Section 16.0 References in this Test Plan). Interim, non-standard methods for assessing the viability of cyst and oocyst (e.g., excystation, DAPI/PI) may be used for verification of inactivation after exposure to UV. However, any interim organism viability method is subject to review by experts of cyst and oocyst viability and subsequent method change. Any non-standard method for assessing cyst and oocyst viability shall be correlated to animal infectivity. Microbial viability analyses are further discussed in Section 4.4 of the "Protocol For Equipment Verification Testing of Microbiological Contaminant Inactivation."

13.0 TASK 5: DATA MANAGEMENT

13.1 Introduction

The data management system used in the verification testing program shall involve the use of computer spreadsheet software and manual recording operational parameters for the water treatment equipment on a daily basis.

13.2 Experimental Objectives

The objectives of this task are 1) to establish a viable structure for the recording and transmission of field testing data such that the Field Testing Organization provides sufficient and reliable operational data for the NSF for verification purposes, and 2) to develop a statistical analysis of the data, as described in "Protocol For Equipment Verification Testing of Microbiological Contaminant Inactivation by Packaged and/or Modular Drinking Water Treatment Systems for Small Public or Private Water Supplies".

13.3 Work Plan

The following protocol has been developed for data handling and data verification by the Field Testing Organization. Where possible, a Supervisory Control and Data Acquisition (SCADA) system should be used for automatic entry of testing data into computer databases. Specific parcels of the computer databases for operational and water quality parameters should then be downloaded by manual importation into Excel (or similar spreadsheet software) as a comma delimited file. These specific database parcels will be identified based upon discrete time spans and monitoring parameters. In spreadsheet form, the data will be manipulated into a convenient framework to allow analysis of water treatment equipment operation. Backup of the computer

databases to diskette should be performed on a monthly basis at a minimum. When SCADA systems are not available, direct instrument feed to data loggers and laptop computers shall be used when appropriate.

For parameters for which electronic data acquisition is not possible, field testing operators will record data and calculations by hand in laboratory notebooks (daily measurements will be recorded on specially-prepared data log sheets as appropriate). Each notebook must be permanently bound with consecutively numbered pages. Each notebook must indicate the starting and ending dates that apply to entries in the logbook. All pages will have appropriate headings to avoid entry omissions. All logbooks entries must be made in black water insoluble ink. All corrections in any notebook shall be made by placing one line through the erroneous information. Products such as "correction fluids" are never to be utilized for making corrections to notebook entries. Pilot operating logs shall include a description of the water treatment equipment (description of test runs, names of visitors, description of any problems or issues, etc.); such descriptions shall be provided in addition to experimental calculations and other items. The original notebooks will be stored on-site; photocopies will be forwarded to the project engineer of the Field Testing Organization at least once per week. This protocol will not only ease referencing the original data, but offer protection of the original record of results.

The database for the project will be set up in the form of custom-designed spreadsheets. The spreadsheets will be capable of storing and manipulating each monitored water quality and operational parameter from each task, each sampling location, and each sampling time. All data from the laboratory notebooks and data log sheets will be entered into the appropriate spreadsheets. Data entry will be conducted on-site by the designated field testing operators. All recorded calculations will also be checked at this time. Following data entry, the spreadsheet will be printed out and the print-out will be checked against the handwritten data sheet. Any corrections will be noted on the hard-copies and corrected on the screen, and then a corrected version of the spreadsheet will be printed out. Each step of the verification process will be initialed by the field testing operator or engineer performing the entry or verification step.

Each experiment (e.g. each challenge test run) will be assigned a run number which will then be tied to the data from that experiment through each step of data entry and analysis. As samples are collected and sent to a laboratory that is certified, accredited or approved by a State, a third-party organization (i.e., NSF), or the U.S. EPA, the data will be tracked by use of the same system of run numbers. Data from the outside laboratories will be received and reviewed by the field testing operator. These data will be entered into the data spreadsheets, corrected, and verified in the same manner as the field data.

13.4 Statistical Analysis

Water quality developed from grab samples collected during test runs according to the Analytical Schedule in Task 4 of this Test Plan shall be analyzed for statistical uncertainty. The Field Testing Organization shall calculate 95% confidence intervals for grab sample data obtained during Verification Testing as described in "Protocol for Equipment Verification Testing of Microbiological Contaminant Inactivation" (Chapter 1). Statistical analysis could be carried out for a large variety of testing conditions.

The statistics developed will be helpful in demonstrating the degree of reliability with which water treatment equipment can attain quality goals. Information on the differences in feed water quality variations for entire test runs versus the quality produced during the optimized portions of the runs would be useful in evaluating appropriate operating procedures.

14.0 TASK 6: QUALITY ASSURANCE/QUALITY CONTROL

14.1 Introduction

Quality assurance and quality control (QA/QC) of the operation of the water treatment equipment and the measured water quality parameters shall be maintained during the Verification Testing program.

14.2 Experimental Objectives

The objective of this task is to maintain strict QA/QC methods and procedures during testing. When specific items of equipment or instruments are used, the objective is to maintain the operation of the equipment or instructions within the ranges specified by the Manufacturer or by *Standard Methods*. Maintenance of strict QA/QC procedures is important in that if a question arises when analyzing or interpreting data collected for a given experiment, it will be possible to verify exact conditions at the time of testing.

14.3 Work Plan

Equipment flow rates and associated signals shall be documented and recorded on a routine basis. A routine daily walk-through during testing will be established to verify that each piece of equipment or instrumentation is operating properly. In-line monitoring equipment such as flow meters shall be checked to verify that the readout matches with the actual measurement (i.e. flow rate) and that the signal being recorded is correct. The items listed below are in addition to any specified checks outlined in the analytical methods.

14.3.1 Daily QA/QC Verifications:

These verifications shall be conducted daily:

- In-line turbidimeters flow rates (verified volumetrically over a specific time period).
- In-line turbidimeter readings checked against a properly calibrated bench-top model.

14.3.2 QA/QC Verifications Performed Every Two Weeks:

These verifications shall be conducted every two weeks:

- In-line turbidimeters (clean out reservoirs and recalibrate).
- In- line flow meters/rotameters (clean equipment to remove any debris or biological buildup and verify flow volumetrically to avoid erroneous readings).

14.3.3 QA/QC Verifications for Each Testing Period:

This verification shall be conducted before each testing period begins:

- Differential pressure transmitters (verify gauge readings and electrical signal using a pressure meter).
- Tubing (verify good condition of all tubing and connections, replace if necessary).

14.4 On-Site Analytical Methods

The analytical method utilized in this study for on-site monitoring of raw water and finished water quality are described in the section below. Use of either bench-top or in-line field analytical equipment will be acceptable for the verification testing; however, in-line equipment is recommended for ease of operation. Use of in-line equipment is also preferable because it reduces the introduction of error and the variability to analytical results generated by inconsistent sampling techniques.

14.4.1 pH

Analysis for pH shall be performed according to *Standard Methods* 4500-H^+ or EPA Method 150.1/150.2. A two-point calibration of any pH meter used in this study shall be performed once per day when the instrument is in use. Certified pH buffers in the expected range shall be used. The pH probe shall be stored in the appropriate solution defined in the instrument manual. Transport of carbon dioxide across the air-water interface can confound pH measurement in poorly buffered waters. If this is a problem, measurement of pH in a confined vessel is recommended to minimize the effects of carbon dioxide loss to the atmosphere.

14.4.2 Temperature

Readings for temperature shall be conducted in accordance with *Standard Method* 2550. Raw water temperatures should be obtained at least once daily. The thermometer shall have a scale marked for every 0.1 ^oC, as a minimum, and should be calibrated weekly against a precision thermometer certified by the National Institute of Standards and Technology (NIST). (A thermometer having a range of -1^oC to +51^oC, subdivided in 0.1^o increments, would be appropriate for this work.)

14.4.3 True Color

True color shall be measured with a spectrophotometer at 455 nm, using a Hach Company adaptation of the *Standard Methods* 2120 procedure. Samples should be collected in clean plastic or glass bottles and analyzed as soon after collection as possible. If samples cannot be analyzed immediately they should be stored at 4^oC for up to 24 hours, and then warmed to room temperature before analysis. The filtration system described in *Standard Methods* 2120 C should be used, and results should be expressed in terms of PtCo color units.

14.4.4 Turbidity Analysis

Turbidity analyses shall be performed according to *Standard Method* 2130 or EPA Method 180.1 with either a bench-top and in-line turbidimeter.

During each verification testing period, the bench-top and in-line turbidimeters will be left on continuously. Once each turbidity measurement is complete, the unit will be switched back to its lowest setting. All glassware used for turbidity measurements will be cleaned and handled using lint-free tissues to prevent scratching. Sample vials will be stored inverted to prevent deposits from forming on the bottom surface of the cell.

The Field Testing Organization shall be required to document any problems experienced with the monitoring turbidity instruments, and shall also be required to document any subsequent modifications or enhancements made to the monitoring instruments.

14.4.4.1 Bench-top Turbidimeters. Grab samples shall be analyzed using a bench-top turbidimeter; readings from this instrument will serve as reference measurements throughout the study. The bench-top turbidimeter shall be calibrated within the expected range of sample measurements at the beginning of pilot plant operation and on a weekly basis using primary turbidity standards of 0.1, 0.5 and 3.0 NTU. Secondary turbidity standards shall be obtained and checked against the primary standards. Secondary standards shall be used on a daily basis to verify calibration of the turbidimeter and to recalibrate when more than one turbidity range is used.

The method for collecting grab samples will consist of running a slow, steady stream from the sample tap, triple-rinsing a dedicated sample beaker in this stream, allowing the sample to flow down the side of the beaker to minimize bubble entrainment, double-rinsing the sample vial with the sample, carefully pouring from the beaker down the side of the sample vial, wiping the sample vial clean, inserting the sample vial into the turbidimeter, and recording the measured turbidity.

When cold water samples cause the vial to fog and prevent accurate readings, the vial must be allowed to warm up by partial submersion into a warm water bath for approximately 30 seconds.

14.4.4.2 In-line Turbidimeters. In-line turbidimeters may be used during verification testing and must be calibrated as specified in the manufacturer's operation and maintenance manual. It will be necessary to periodically verify the in-line readings using a bench-top turbidimeter; although the mechanism of analysis is not identical between the two instruments the readings should be comparable. Should these readings suggest inaccurate readings then all in-line turbidimeters should be recalibrated. In addition to calibration, periodic cleaning of the lens should be conducted using lint-free paper, to prevent any particle or microbiological build-up that could produce inaccurate readings. Periodic verification of the sample flow should also be performed using a volumetric measurement. Instrument bulbs should be replaced on an as-needed basis. It should also be verified that the LED readout matches the data recorded on the data acquisition system, if the latter is employed.

14.5 Chemical and Biological Samples Shipped off-Site for Analyses

The analytical methods that shall be used during testing for chemical and biological samples that are shipped off-site for analyses are described in the section below.

14.5.1 Organic Parameters: Total Organic Carbon and UV_{254} Absorbance

Samples for analysis of TOC and UV_{254} absorbance shall be collected in glass bottles supplied by the state-certified or third party- or EPA-accredited laboratory and shipped at 4°C to the analytical laboratory. These samples shall be preserved, held, and shipped in accordance with *Standard Methods* 5010 B. Storage time before analysis shall be minimized, according to *Standard Methods*.

14.5.2 Microbial Parameters: Viruses, Bacteria, Protozoa, and Algae

Samples for analysis of any microbiological parameter shall be collected in bottles supplied by the analytical laboratory. Microbiological samples shall be refrigerated at approximately 2 to 8°C immediately upon collection. Such samples shall be shipped in a cooler and maintained at a temperature of approximately 2 to 8°C during shipment. Samples shall be processed for analysis by a laboratory that is certified, accredited or approved by the state, a third party organization (i.e., NSF) or the USEPA within 24 hours of collection. The laboratory shall keep the samples at approximately 2 to 8°C until initiation of processing. TC densities shall be reported as most probable number per 100 mL (MPN/100 mL) or as total coliform densities per 100 mL. TC is an optional sampling parameter.

Methods for assessing the viability of the selected bacteria and viruses shall be specified by the laboratory(ies) performing the analysis and shall be specified in the FOD. The FTO may select a laboratory that is certified, accredited or approved by the state, a third party organization (i.e., NSF) or the USEPA for analysis of microbial contaminants in water samples.

Methods for assessing the viability of cysts and oocysts are non-standard but may be used in verifying claims that an on-site halogen generation system inactivates protozoan cysts and oocysts if the method has undergone peer review. A summary and comparison of viability methods is presented in research completed by the following researchers: Korich et al. (1993), Nieminski and Ongerth (1995), Slifko et al. (1997) and others (see Section 12.0 References in this Test Plan). Any non-standard method for assessing cyst and oocyst viability shall be correlated to animal infectivity.

Algae samples shall be preserved with Lugol's solution after collection, stored and shipped in a cooler at a temperature of approximately 2 to 8°C, and held at that temperature range until counted.

14.5.3 Inorganic Samples

Inorganic chemical samples, including alkalinity, hardness, aluminum, iron, and manganese, shall be collected and preserved in accordance with *Standard Method* 3010B, paying particular attention to the sources of contamination as outlined in *Standard Method* 3010C. The samples shall be refrigerated at approximately 4°C. Samples shall be processed for analysis by a laboratory that is certified, accredited or approved by the state, a third party organization (i.e., NSF) or the USEPA within 24 hours of collection. The laboratory shall keep the samples at approximately 4°C until initiation of analysis.

15.0 OPERATION AND MAINTENANCE

The Field Testing Organization shall obtain the Manufacturer-supplied Operation and Maintenance (O&M) manual to evaluate the instructions and procedures for their applicability during the verification testing period. The following are recommendations for criteria for O&M Manuals for package drinking water treatment equipment employing UV technology.

15.1 Maintenance

The Manufacturer shall provide readily understood information on the recommended or required maintenance schedule for each piece of operating equipment including, but not limited to, the following, where applicable:

- lamps
- control valves
- cooling fans
- quartz sleeves or tubes
- instruments, such as turbidimeters, UV sensors
- water meters
- electrical equipment
- mechanical wipers

The Manufacturer shall also provide readily understood information on the recommended or required maintenance for non-mechanical or non-electrical equipment, including but not limited to, the following, where applicable:

- screens
- piping
- treatment chamber

15.2 Operation

The Manufacturer shall provide readily understood recommendations for procedures related to proper operation of the package plant equipment. Among the operating aspects that should be addressed in the O&M manual are:

UV Lamps:

- Hours of operation - how should this be checked
- UV irradiance - how check and/or calibrate
- cleaning - how and when to clean
- changing - how to determine need to change

Screens (where applicable):

- cleaning - when is it needed
- measurement of head loss during operation
- integrity - how to gauge it

Control Valves:

- open/close indication
- sequence of operations

Exposure Time:

- correlation of flowrate and exposure time
- maintenance/calibration of flow meter

Cooling Water System:

- monitoring/maintenance of proper water temperature
- monitoring cooling water flow
- recirculation pumps

The Manufacturer shall provide a troubleshooting guide; a simple checklist of what to do for a variety of problems, including but not limited to:

- no flow to unit
- sudden change in flow to unit
- no electric power
- excessive headloss across screens
- loss of cooling water flow
- filtered water turbidity too high
- sudden reduction in UV irradiance
- automatic operation (if provided) not functioning
- valve stuck or will not operate

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APPENDIX 4A

INTERIM PROCEDURES FOR ASSESSING INACTIVATION OF CYSTS & OOCYSTS

A1 Work Plan

A1.1 Microbial Challenge Tests For cysts and oocyst only, the microbial challenge test may be performed three times at the best operating conditions specified by the manufacturer and based on the results from the Initial Operations (section 5). Only one process control test (section 12.3.3.1) may be performed where the UV lamp is turned off. One microbial challenge test may also be performed at an operating condition less than the manufacturer recommends. This condition may be determined by increasing the flow through the reactor or decreasing the power to the UV lamp, i.e., reduce irradiance to less than optimum.

A1.2 Test Operation and Sample Collection

A1.2.1 Influent Sample Collection. Determination of percent viability of protozoan cysts and or oocysts shall be made on a trip blank equivalent to the spike dose vial (see 12.3.3.2).

A1.1.2.2 Effluent Sample Collection. For protozoan spiking experiments, EPA Method 1622 or any other method that has been evaluated through the peer-reviewed process (e.g., Nieminski and Ongerth, 1995) may be followed for sample collection from the spiked water streams. The sample collection system shall be plumbed to allow installation of housings and filters for capture of sufficient flow for microbiological analysis. The FTO shall provide an indication of the recovery efficiency achievable under the sample collection method selected for use during protozoa seeding studies. The specific capture filter recovery system shall be fully described in the FOD by the FTO. In addition, the FOD shall include a plan of study for verification testing with a minimum of three standard recovery efficiency tests from the microbiological laboratory. If sufficient system pressure is not available to drive flow through the capture filters, centrifugal pump(s) may be used to boost pressure. In addition, a sample port will be plumbed upstream of the filters to allow sampling for chemistry parameters and bacteria and virus samples.

A1.2.3 Post-Test Sample Handling. The Field Testing Organization shall then take steps to contain and/or sanitize any organisms remaining in the pilot system. Depending on the unit (design and materials), sanitization may be done using steam or hot water (80ºC for 10 min). The QA/QC plan should address how this sanitization procedure is to be done to insure inactivation of live organisms and subsequent removal of inactivated organisms from the unit, and biosafety concerns for both humans and the environment.

APPENDIX 4A (continued)

A2 Viability of Cysts and Oocysts

Methods for assessing the viability of cysts and oocysts are non-standard but may be used in verifying claims that a package drinking treatment systems (package plants) inactivates protozon cysts and oocysts. A summary and comparison of viability methods is presented in research completed by Korich et al., 1993 (see Section 16.0 References in Chapter 4 of this document).